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SIXTH WORKSHOP ON SEEDLING PHYSIOLOGY AND GROWTH PROBLEMS IN OAK PLANTINGS, RHINELANDER, WISCONSIN, SEPTEMBER 18-20, 1995 (ABSTRACTS)

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PREFACE

The sixth workshop on seedling physiology and growth problems in oak plantings was held at Treehaven, University of Wisconsin - Stevens Point Natural Resource and Education Center near Rhinelander, Wisconsin, on September 18-20, 1995. This series of workshops began in November, 1979 at the University of Missouri, Columbia, to provide scientists working with oak regeneration the opportunity to update each other on current findings and approaches to research, to exchange ideas, and to coordinate efforts on seedling physiology and growth problems of oak. The 1995 workshop presentations addressed three general problem areas: (1) genetics and physiology, (2) nursery practices, and (3) silviculture and field practices of oak. Invited speakers for a round table discussion devoted to nursery practices were: Paul Kormanik, USDA Forest Service, Southern Forest Experiment Station, Athens, GA 30602; Daniel Krueger Jr., Northwoods Nursery, Rhinelander, WI 54501; and Patricia Tomlinson, USDA Forest Service, North Central Forest Experiment Station, Rhinelander, WI 54501. The invited speakers for a second round table discussion that addressed silviculture and field practices were: David Buckley, USDA Forest Service, North Central Forest Experiment Station, Rhinelander, WI 54501; Thomas Jahnke, Hennepin Parks, Maple Plain, MN 55359; and Douglas McCreary, University of California - Berkeley, Browns Valley, CA 95918. A one day field tour followed the workshop where participants viewed three unique oak ecosystems. The first two stops were at northern hardwood sites, one a fertile mesic site - The Willow Springs Ecosystem Processes Study, the other a less fertile dry-mesic site - The Bird Lake Oak Regeneration Site. The tour concluded at a thinned red pine plantation where the association between pine and oak is being studied.

ACKNOWLEDGMENTS

Ron Teclaw and J.G. Isebrands, workshop coordinators, wish to gratefully acknowledge the invaluable assistance of Kathy Heise with the planning and arrangements for the meeting, and Ed Bauer for design and production of the abstract cover. Workshop participants are grateful to Doug McCreary and the University of California for inviting us all to California for the seventh workshop in 1998.

REVIEW PROCEDURE

Each abstract in this general technical report was critically reviewed by at least two editors. Revised abstracts were reviewed by each author and then submitted camera-ready to North Central Forest Experiment Station, USDA Forest Service, for publication. Individual authors are ultimately responsible for the accuracy of their papers.

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Mention of pesticides, fertilizer, equipment or trade names does not imply endorsement of these products or their applications by the USDA Forest Service.

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THE STRUCTURE OF GENETIC VARIATION IN JUVENILE HEIGHT GROWTH OF NATURAL POPULATIONS OF NORTHERN RED OAK

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From 1990 to 1994, a series of progeny tests of open-pollinated *Quercus rubra* L. (NRO) were established in plantations on recently cleared forest land at three locations in Pennsylvania. The principal objective of the study is to identify in situ seed production plus trees whose progeny exhibit rapid juvenile growth rate. In addition to some collections from planted trees, the tests contain progeny sets from 154 naturally occurring mother trees in 23 subpopulations representing four physiographic provinces.

This series of experiments has provided us with the opportunity to examine the structure of genetic variation in growth rate in this species, about which there is almost no published information. For plantation age 3 heights in this series of studies (all except 1994 plantations), the within-subpopulation variance component accounted for all of the estimable genetic variance. (The average among-subpopulation variance component was slightly negative.) In other words, locally occurring subpopulations of NRO typically contain the entirety of the genetic variability in this trait that is available within the larger population represented by these collections, which covers most of Pennsylvania. These results are qualitatively similar to other published and unpublished information from NRO progeny tests. We conclude that natural selection has favored high genetic variability in growth potential within NRO populations.

CARBON ASSIMILATION BY MULTIPLE-FLUSH NORTHERN RED OAK SEEDLINGS EXPOSED TO REPEATED DRYING CYCLES AND ELEVATED ATMOSPHERIC CARBON DIOXIDE

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To better understand how global climate change may alter the ecological fitness and distribution of northern red oak (*Quercus rubra* L.) in the western, more xeric, extent of it's range, we are studying the interactive effects of two stressors, elevated CO_2 and water stress, on physiological, developmental and growth processes. In this paper, we present our findings with respect to leaf-level carbon acquisition processes and their variation among developmental stages of multiple growth flushes.

Half-sib northern red oak seedlings were grown through three growth flushes from acorns in controlled environment chambers with 400, 525 or 700 ppm CO_2, 16 h daylength at 400 to 500 $\mu E\ m^{-2}\ s^{-1}$ PAR and 27/21°C thermocycle. Seedlings were either well-watered (WW) or water-stressed (WS) using repeated drying cycles. Measurements of net photosynthesis and stomatal conductance were made when seedlings reached the lag (LG) stage of each flush (1LG, 2LG, and 3LG) and during the leaf linear stage of the third flush (3LL).

The first flush of growth was completed during the first drying cycle without manifestation of water stress. By 2LG carbon assimilation rate (P_n) was generally lower for WS plants, relative to WW plants and this trend continued through 3LG. We observed a general increase in P_n for both WW and WS plants with elevated CO_2, although this increase was significant at 2LG and 3LG only. For WW plants, the increased P_n occurred between 400 to 525 ppm CO_2 while for WS plants, the increased P_n occurred between 525 to 700 ppm CO_2. In WS plants, P_n of first flush leaves increased 160 percent from 2LG to 3LL, possibly indicating carbon sink strength regulation of P_n in older flush leaves under water stress.

Stomatal conductance (g_s) was greater for WW than WS plants at 2LG and 3LG. There was a tendency for decreasing g_s with increasing CO_2. For WW seedlings, the decrease in g_s with change in CO_2 was relatively linear over the 400 to 700 ppm CO_2 range. For WS plants, the decrease in g_s tended to be greatest with a change in CO_2 from 400 to 525 ppm and lesser with an increase from 525 to 700 ppm CO_2. As with P_n, g_s of WS first flush leaves increased approximately 1.5 fold with development from 2LG to 3LL suggesting a linkage between stomatal limitation and increased P_n during maximum rate of leaf expansion. The trends for decreased g_s and increased P_n resulted in a general increase in photosynthetic water-use efficiency with elevated CO_2.

PHOTOSYNTHESIS, SUCROLYSIS AND DRY WEIGHT ALLOCATION IN *QUERCUS RUBRA* AND *Q. ALBA* SEEDLINGS GROWN UNDER SHADE

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Sixteen acorns of northern red oak (NRO) or white oak (WO) were sown into 1 m x 1 m wooden microplots in January 1993. There were 12 microplots for each species. Seedlings were grown under full sun (controls), 30% shade or 70% shade. Half of the seedlings were harvested at the end of the first year and the rest of seedlings were grown for another year. For both species, no differences in photosynthetic rate between seedlings grown under 30% shade and full sun were found. However, 70% shaded NRO and WO seedlings had 40% lower photosynthetic rates than the controls. Two years after treatment, 70% shade NRO and WO seedlings had two-fold less seedling and taproot dw and four-fold less lateral root dw than full sun and 30% shade seedlings. Although 70% shade grown NRO and WO seedlings had greater dw per leaf, these seedlings had fewer leaves, less specific leaf dw (mg/cm^2) and less total leaf dw than other seedlings. Seedling and stem dw of 30% shaded NRO were significantly greater than those of full sun seedlings the first year but there were no differences for the second year. It was probable that the 30% shade screen provided seedlings some cooling effects from summer heat of 1993. Although not statistically significant, 70% shade seedlings had greater height and smaller root collar diameter. Longer but thinner stem and larger leaf size are characteristics of etiolation resulted from low light intensity. The effects of shading on NRO and WO seedlings were so great that understory planting of oak seedlings for regeneration needs to be reassessed.

Pathways for sucrose metabolism (sucrolysis) were identified with stem and taproot of control NRO seedlings. Sucrose synthase (SS) is the dominant sucrose cleavage enzyme and showed strong seasonal patterns. High SS activity was detected in stem and taproot cambial tissues from late April through late September. Stem SS peaked two weeks earlier in the spring than taproot SS. Activities for several glycolytic enzymes were also detected in NRO. The effects of shading on the temporal and spatial patterns of sucrolysis need to be determined.

LIGHT EFFECTS ON SEEDLINGS OF BOTTOMLAND OAKS

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Two studies were implemented to investigate the role of light in the ecophysiology of bottomland oak regeneration. Study 1, which was replicated in time, investigated growth and biomass distribution in *Quercus pagoda* under 100%, 53%, 27%, and 8% of full sunlight. After 2 growing seasons, plant dry weight, height, and root-collar diameter generally decreased in the order 53% > 27% > 100% > 8% sunlight. Root/stem ratios decreased in the order 100% > 8% > 53% > 27%. Allometric relationships of dry weight distribution were largely independent of plant size, and light effects were much more pronounced in second than in first year seedlings. In Study 2, potted *Q. lyrata*, *Q. nuttallii*, and *Q. pagoda* seedlings were grown in 100% or 20% of full sunlight to assess morphological and physiological leaf plasticity to the light environment. For seedlings grown with 20% of full sunlight, *Q. pagoda* showed the largest increase in blade area (130%) and degree of non-planer blade display (22%), but *Q. lyrata* and *Q. nuttallii* exhibited the greatest shifts in leaf orientation (> 30°). Light response curves for *Q. lyrata* and *Q. nuttallii* leaves were similar regardless of light environment, but shade-grown *Q. pagoda* leaves showed significant decreases in dark respiration, quantum yield, and the saturating light level. Results from these studies suggest that regeneration of *Q. pagoda* on mesic sites may be limited by preferential allocation to root growth and poor photosynthetic acclimation of shade-grown leaves to increased light intensities.

BOTRYOSPHAERIA CANKER OF NORTHERN RED OAK

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A vigorously growing northern red oak *(Quercus rubra* L.*)* plantation in Oconee County, SC, suffered extensive damage from *Botryosphaeria dothidea* (Moug. ex Fr.) Ces. & de Not canker. The plantation involved 793 trees and 8 half-sib families of northern red oak (NRO) located on a mesic, highly productive site, with pre-disease height averaging 3.5 meters after the third growing season. The disease became evident during the third growing season when a single tree exhibited branch flagging. By the fourth year, extensive branch symptoms were evident throughout the entire plantation. All families were affected by the disease. Disease incidence after 5 years was 100%. The plantation, now in the 8th growing season, is decimated by the disease. No salvageable growing stock remains.

B. dothidea is an opportunistic pathogen, generally attacking stressed trees, causing minor diebacks and cankers during stress situations such as drought, defoliation, or freezing. We could not ascribe any of these factors to the present epidemic in this plantation. Our hypothesis is that rapid growth occurring in this plantation, coupled with close proximity of native vegetation harboring inoculum of the fungus, resulted in the present outbreak. The exact disease processes involved in the outbreak experienced in this plantation are unknown. Rapid growth rates that were present earlier in the life of the plantation could have produced more succulent tissues and possibly increased natural wounding. On the other hand, an unknown transient factor or set of factors could have triggered the disease outbreak.

This outbreak illustrated the destructive potential of pathogens, normally judged as innocuous or secondary, when susceptible hosts are placed in intensively managed regimes. Because of the unknown factors responsible for the disease in this NRO plantation, it is important to understand possible predisposing factors that might be involved. Our preliminary data suggests some infections in NRO may arise in the nursery and may contribute to losses in the early life of plantings of this species. Further research on the biology of this disease is essential to avert undesirable outcomes in the artificial regeneration of NRO.

DROUGHT RESPONSE AND DRY WEIGHT ALLOCATION OF MATURE AND JUVENILE VEGETATIVE PROPAGULES OF NORTHERN RED OAK

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We compared gas exchange during imposed drought and dry weight allocation among plant parts for similar-aged northern red oak propagules (grafts, rooted cuttings, and seedlings) from juvenile and mature origins. Cuttings from seedlings and a mature tree were rooted in September 1991 (RJ and RM, respectively). Scions from seedlings (GJ) and a mature tree (GM) were grafted onto 1-year-old rootstocks in April 1992. Seedlings (S) were grown from acorns sown in May 1992. All propagules were repotted in mid-summer 1992, grown at near field capacity until autumn, and overwintered in an unheated greenhouse. In July 1993, five representative plants of each type were placed under a 16-hour photoperiod regime, and maintained with soil moisture near field capacity until 11 Oct 1993 when water was withheld. At 2- to 5-day intervals under saturated or near saturated light conditions during midday hours, area-based net photosynthesis (A) and stomatal conductance (g) were measured on 3 leaves from each plant. The weight of each pot was recorded 24 hours after initial soil saturation and immediately after each periodic gas exchange measurement to determine change in plant/soil relative water content (RWC). Leaf area and stem, leaf, and root dry weights were determined for each plant after reaching incipient wilting ($A < 0.0$ umol$\cdot m^{-2}\cdot sec^{-1}$ on two consecutive measurements).

The GM propagules had higher rates of A and g throughout most of the drought cycle compared to all other propagules, all of which had very similar rates. Juvenile propagules (RJ, S, and GJ) averaged significantly greater root, shoot, leaf, and total dry weights and total leaf area than mature propagules (RM and GM). Root, stem, and leaf dry weight allocation (as a percentage of total dry weight) was generally similar between juvenile and mature groups and among juvenile propagule types but differed between mature propagule types (GM vs RM). The GM propagules had significantly greater root:shoot ratios compared to most other treatments. The leaf weight per area (LWA) of GM leaves was similar to leaves from it's mature ortet, but was significantly higher than all other propagule types including RM. Results indicate that rooted and grafted mature propagules respond differently to imposed drought and exhibit different growth patterns. Results also suggest that the choice of propagule type may affect predictions in scaling studies.

EFFECTS OF ACORN PLACEMENT AND THE AMOUNT OF HARDWOOD LITTER ON THE GERMINATION AND EARLY ESTABLISHMENT OF WATER OAK SEEDLINGS

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The influence of acorn placement (between the fresh litter layer and the fermentation, or older litter layer, on the soil surface, and buried in the soil) and the amount of hardwood litter (0, 10, 20, 30, 40, and 50 Mg/ha) on germination and early establishment of water oak (*Quercus nigra* L.) seedlings was studied in a split-plot completely randomized block design. Only 20% of the acrons placed within the litter were established at the end of the first growing season compared to >80% for acorns placed on the soil surface or buried in the soil. Few differences in establishment were found based on litter weight with percentages ranging from 58% for 0 and 20 Mg/ha litter to 68% for 50 Mg/ha litter. Stem length decreased with increasing litter weight. Seedling growth in 10 Mg/ha was the greatest (38 cm) and decreased with greater litter weight (20, 30, 40 and 50 Mg/ha with 37, 35, 34, and 31 cm in length, respectively). The shortest seedlings (25 cm) occurred in the no litter treatment. A similar trend was also found for root-collar diameter. Results from this study indicate the method of acorn placement and the condition of the forest floor can have an effect on water oak seedling establishment and first-year growth.

ARTIFICIAL REGENERATION OF NORTHERN RED OAK (*QUERCUS RUBRA* L.) ON INTERMEDIATE SITES: RELATIONSHIPS BETWEEN DAMAGING FACTORS AND POTENTIAL COMPETITORS

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Competing vegetation and herbivores are thought to significantly hinder oak regeneration. How these factors interact with each other and abiotic factors is less clear. It has been suggested that regeneration may be most successful on sites intermediate in productivity where disturbances and intermediate resource levels limit competitors. Though competition may be less intense on these sites, additional factors which limit regeneration success can be important.

Artificial regeneration of northern red oak was studied on intermediate sites in northern Lower Michigan. Objectives were to quantify: (1) regeneration success in pine versus oak stands, (2) impacts of herb, shrub, and overstory layers and (3) relationships between these layers, herbivores, and abiotic factors that affect regeneration. In the spring of 1991, acorns and 2-0, bareroot nursery seedlings were planted in 3 natural oak and 3 red pine (*Pinus resinosa* Ait.) plantation blocks. Each block contained 4 overstory treatments: clearcut, 25% cover, 75% cover, and uncut. Each overstory treatment contained 4 understory treatments: herb layer removal, shrub layer removal, litter removal, and control. Seedling survival, performance, and damage were quantified along with potential competitors, light, soil moisture, nutrients, soil temperature, air temperature, and precipitation during the 1991-92 growing seasons.

Seedling success was less in pine than oak blocks as deer browsing was more intense and soil resource levels were lower in pine blocks. Though overall performance increased with overstory and understory vegetation removal, mortality and variability in performance also increased due to increased deer browsing and frost damage. Herb and shrub layer effects were most prominent in clearcut and 25% cover plots, and herb layer density increased with shrub layer removal. The shrub layer was more important than the herb layer in intercepting light and in protecting against frost and deer browsing. Relative, competitive effects of these understory layers were partially confounded by interactions between the two layers and the protective effect of the shrub layer. Litter removal decreased seedling performance. Clearly, removal of competing vegetation can potentially increase damage, mortality, and variability in seedling performance. Thus, these interactions should be considered when selecting the degree of competition removal.

A REASSESSMENT OF LIGHT-SENSITIVE DIAZO PAPER FOR MEASURING INTEGRATED LIGHT IN THE FIELD

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In 1961, Friend published a simple, inexpensive method for measuring integrated light values in the field by using light-sensitive diazo paper that was calibrated against a standard light-measuring device. Since the introduction of this method to the ecological community, many people have used this apparently straight-forward, simple technique to provide them with inexpensive, multiple-sample measurements of light in the field. The core assumption of this technique is that the number of diazo sheets exposed is a function of the total quantity of radiation (i.e., duration * intensity). Consistent with Friend's results, we found a linear relationship between the number of layers of exposed diazo paper and log10 of accumulated PPFD (mol/m^2), but further investigation indicated that the method is a poor predictor of accumulated light. Field and growth chamber tests indicate that diazo paper exposure is not a measure of accumulated PPFD, but is a response to maximum irradiance. A stronger linear relationship exists between the number of layers of exposed diazo paper and maximum irradiance (r^2 = 0.94) than exists between the number of layers of exposed diazo paper and accumulated photosynthetic photon flux density (PPFD) (r^2 = 0.73) or the log10 transformation of accumulated PPFD (r^2 = 0.92). Under field conditions, full sunlight resulted in exposure of no additional layers of diazo paper after about noon. The strong relationship between the number of layers of exposed diazo paper and maximum irradiance, in conjunction with field and growth chamber results, suggests that diazo paper records irradiance at a slow rate, giving the impression that it is recording accumulated PPFD. Thus, diazo paper should not be used to measure accumulated PPFD under field conditions, especially for periods that include a significant amount of time after noon or under conditions of light flecks or varying irradiance. The diazo technique is far more sensitive to a pulse of maximum radiation (i.e., the maximum intensity) than the total radiation received. Because maximums are highly correlated with daily or integrated totals, in both open and shaded environments, results using diazo paper have largely gone unchallenged. This paper provides a firmer understanding of this technique and, therefore, some potentially important limitations.

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ACORN PRODUCTION AND MANAGEMENT PRACTICES IN A NORTHERN RED OAK SEEDLING SEED ORCHARD

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Little is known about seed orchard management in oak species. Seed orchards of North American oaks are rare and usually are comprised of grafted clones. In the late 1980's, an open-pollinated progeny test on the Cherokee National Forest was converted to a seedling seed orchard. Initially, the orchard was conservatively thinned to leave the best trees in a maximum number of families. Another thinning was conducted in 1993 to allow maximum crown development and to removed suppressed trees. Research and management objectives include: (1) to collect acorns for use in reforestation, (2) to study the biology of acorn production, and (3) to develop seed orchard management protocols. Studies on flower/acorn retention, insect control, acorn production and quality, insect diversity, foliar disease and scale infestation have been conducted. Observations of acorn production made in 1985 and 1989-95 indicate family differences in reproductive maturity and acorn production. In 1992, the orchard began producing acorn crops large enough for collection and planting for large-scale reforestation.

RELATION BETWEEN ACORN QUALITY AND DELAY IN COLLECTION AFTER NATURAL SEED FALL IN NORTHERN RED OAK (*QUERCUS RUBRA*)

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Insufficient information is known about seed quality and the timing of seed collection in oak species. Acorns are vulnerable to environmental conditions that could diminish seed quality. An experiment was designed to evaluate environmental effects of weather variables, shading, and the timing of acorn collection on moisture content and seedling development of northern red oak (*Quercus rubra* L.) acorns. Seed lots from 10 families were tested between October 19, and November 18, 1994 and sampled at 2 day intervals. Samples were examined to determine environmental effects on moisture content and future seedling development. Results indicated no significant relationship between moisture content, weather variables, shading, timing of collection, and seedling development. The experiment will be replicated in fall 1995 using the same families. The results can be utilized in the management strategies for oak seed orchards.

OAK SEED TESTING: THE KEY TO QUALITY BARE ROOT SEEDLINGS

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The Indiana Division of Forestry operates two bare root nurseries that produce approximately 1.5 million oak seedlings of 12 species per year. The acquisition, testing, and precise sowing of the seed required to produce this number of seedlings is a unique process. Local collectors are encouraged to only deliver viable, filled seeds to the nurseries and are paid on that basis, rather than by volume or weight. The number of viable seeds in each seedlot is determined by destructive sampling and weight measurements. Depending upon the species and total seedlot weight, a prescribed number of samples are drawn from the lot. Sample sizes range from 10 to 50 random seeds per sample, and the number of samples per lot vary from 5 to 90 based upon the total seedlot weight. In addition to providing information on payment to the seed collector, these data are used to calculate the total number of good seeds in each seedlot for sowing purposes. The total number of good seed in each seedlot is calculated by the following equation:

Average # Seeds/lb. X Total Weight (lbs.) X Average % Good Seed

All seedlot information is maintained on computer file until sowing. Knowledge of the percent good seed and total number of good seeds available for sowing is used to calibrate the oak seed planting machine by nursery personnel, which results in a predictable sowing density in the seedbeds. In addition, this information is utilized by nursery managers to develop future production schedules and calculate unit costs, by focusing on emergence data and seedling recovery factors.

Seed testing data is used to calculate precise sowing rates. This allows for control of seedbed density, which leads to fairly predictable stem caliper development and an abundance of first order lateral roots. Both of these variables are highly important for assessing potential field survival and growth.

EFFECTS OF MULCH AND SOWING METHOD ON 1+0 NORTHERN RED OAK SEEDLINGS

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Methods for producing northern red oak (*Quercus rubra* L.) planting stock are highly variable as are the seedlings produced. We studied the impacts of sowing methods (sowing depths of 2.2 to 6.4 cm and seed bed densities of 75 or 150 acorns m^{-2}) and mulch treatments on seedling characteristics. The study was conducted twice during different years using different half-sib seed sources and mulch treatments each year. Mulch treatments were: hardwood sawdust aged 2 years, ground corncob aged 1 year, and no mulch for year 1; hardwood sawdust aged 3 years and no mulch for year 2. All mulches were applied approximately 2.5 cm deep immediately after sowing in the fall; mulches remained in place from application through the growing season except during year 2 where one mulch treatment involved removal of sawdust mulch in the spring prior to the growing season. Seed was sown in the fall; seedlings were lifted in the spring as 1+0 stock by undercutting at 20 cm.

The seedlings from the two years were significantly different. Shoot height, number of first-order lateral roots (FOLR), and shoot to root biomass ratios were greater for year 1 seedlings while root collar diameter, and root biomass were greater for year 2 seedlings. Mulch significantly improved seedling emergence during year 1 but not during year 2. Increased sowing depth delayed seedling emergence both years.

Mulch, especially sawdust mulch that was not removed before the growing season, decreased root biomass significantly. This decrease was associated with an increased shoot/root biomass ratio. Number of FOLR decreased slightly in plots where sawdust mulch remained during the growing season compared to plots with corncob mulch (year 1) or to plots where sawdust mulch was removed prior to the growing season (year 2). Seedlings in unmulched plots had more FOLR than sawdust mulched seedlings during year 1 but the same or fewer FOLR during year 2.

Seedling quality was significantly affected by sowing methods and mulch. Deeper sowing appeared to be associated with greater shoot height, larger root collar diameter, and greater shoot biomass in both years. Lower seedling densities appeared to be associated with larger root collar diameter, more FOLR, and greater shoot, root, and plant biomass. Aging hardwood sawdust at least 3 years prior to use as mulch was important, particularly for root growth. This study suggests that sowing at low seedbed densities and covering the seed with mulch, especially during the winter, improves seedling quality in our region.

WILL OAK SEEDLING QUALITY MAKE A DIFFERENCE IN SUCCESSFUL REGENERATION?

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In the past decade we have developed a protocol for growing 1-0 *Quercus* seedlings that can readily produce seedlings exceeding 1 m in height with root collar diameters ranging from 1.0 to 2.0 cm. We have also found that planting Northern red oak seedlings (NRO) under an overstory canopy with basal area reduced to 70 sq ft/acre and all understory vegetation eliminated, results in no net height growth after 5 years regardless of seedling size. Excavation of seedlings at age 5 revealed that most of the original lateral roots had died back leaving only small lateral roots at the point where the taproot had been cut prior to planting.

In the adjacent clearcut area, about 50% of the larger sized outplanted seedlings were free to grow at age 5 and were up to 4.5 m tall despite competition from approximately 20,000 sprouts of yellow poplar seedlings per acre. Root excavation at age 2 to 5 has never shown the decline in root numbers as observed in the understory planting trials. Several large crowned individuals have produced acorns in their fifth year. In contrast, only a few of the smaller planted seedlings in the clearcut survived. In the same area, few of the naturally regenerated oak seedlings were still present but small in size. The growth of large size NRO seedlings in a traditional plantation with weed control and second year fertilization has been encouraging.

Based on theses observations, in 1995, the Institute of Tree Root Biology, USDA Forest Service Region 8, and the University of Tennessee established 18 trials throughout Region 8, using the top 50% of the nursery-grown NRO seedlings from 78 different mother trees. At each location, 1,250 quality seedlings from 25 different mother trees were planted in clearcuts of 3 to 5 acres. To facilitate planting, seedling taproot and lateral roots were trimmed to 30 to 35 cm and 15 to 20 cm, respectively. We expect that these 1-0 NRO seedlings of 1 m or taller can become established in clearcuts and can compete with most hardwood sprouts and yellow poplar seedlings developed from seed present in the litter layers.

EFFECTS OF FLOODING DURATION AND SEASON ON ACORN GERMINATION OF BLACK, CHERRYBARK, NORTHERN RED, AND WATER OAKS

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Effects of flooding duration (0, 10, 20, and 30 days) and season (winter and spring) on acorn germination were tested in a completely randomized split plot design for two upland oaks [black and northern red (*Quercus velutina* Lam. and *Q. rubra* L.)] and two bottomland oaks [cherrybark and water (*Q. pagoda* Raf. and *Q. nigra* L.)]. Half-sib acorns from individual trees were collected in November 1994 and stratified for 30 days before applying treatments. Northern red oak acorns for the spring flooding treatment were not stratified because the radicles had already emerged. Acorns were flooded from mid-January to mid-February 1995 for winter flooding and from mid-March to mid-April for spring flooding at a depth of 15 cm along the edge of a small pond. After treatment, acorns were sowed in sand-filled plastic cups and germinated. Acorn emergence was measured weekly, and the soundness of ungerminated acorns was evaluated at study termination. Flooding duration and season affected radicle and epicotyl emergence of the upland oaks greatly, but effects were principally limited to spring flooding. Embryonic axes of the upland oak acorns were severely damaged with as little as 10 days of spring flooding and almost no epicotyls developed. Although embryonic axes were severely damaged, radicles developed from the cotyledons. Spring flooding also significantly increased the number of the rotten acorns for the upland oaks. By contrast, germination of the bottomland oaks was slightly improved by flooding during both seasons. Results of the study suggest that germination ecology can be an important factor in determining the distribution of oak species.

LONG-TERM RESPONSE OF WHITE OAK TO AUXIN AND OTHER PREPLANTING TREATMENTS

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Early, vigorous root growth of planted seedlings is critical for good establishment and subsequent growth of white oak (*Quercus alba* L.). Preplant application of the auxin, indolebutyric acid (IBA), has been shown to improve early root growth in the greenhouse of both 1-0 white oak and black walnut seedlings. In 1982, a study was initiated to evaluate preplant treatment effects, including application of IBA, on 1-0 and 2-0 white oak seedlings in field plantings. Two thirds of the 1-0 seedlings were from fall- or spring-sown acorns from five white oak trees from Lawrence County, Indiana. The 2-0 seedlings were from five white oak trees from Jackson County, Illinois. IBA was applied by either soaking seedling roots for 30 min in a solution containing 3 g K^+-IBA per L water, dipping roots in a Terrasorb-200 solution (14 g per L) containing 3 g K^+-IBA per L water, or inserting two IBA- impregnated toothpicks (previously soaked in 3 g K^+-IBA per L ethanol) into the top half of the taproot. The same treatments without IBA were applied to the control seedlings. All seedlings were outplanted in April 1983 on an upland site in southern Illinois at 1.0 x 1.5-m spacings. Seedlings were planted with the root collar 2.5 cm deep. One half of the seedlings were top-pruned to a height of 12.5 cm after planting. Weed competition was controlled for 3 years with glyphosate and simazine.

After 12 years, tree basal diameters ranged from 1.4 to 16.4 cm and averaged between 7.6 and 8.7 cm across the six treatments. The trees established as 2-0 seedlings had an average basal diameter of 10.4 cm compared to an average diameter of 7.5 cm for trees planted as 1-0 seedlings. Fall- or spring-sowing of white oak acorns from five half-sib progenies had no influence on basal diameters. However, differences were found in basal diameters among the five half-sib progenies. There was no interaction with IBA, method of preplant, or pruning treatments. Similar results were found 1 and 5 years after establishment. Use of auxins to enhance root regeneration or to alter root morphology apparently does not affect the long-term growth of field-planted white oak seedlings.

UNDERCUTTING AND SHOOT CLIPPING INFLUENCE SURVIVAL OF WHITE OAK ONE YEAR AFTER OVERSTORY REMOVAL

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Two-year-old white oak (*Quercus alba* L.) seedlings were outplanted under two shelterwoods reduced to 60 percent stocking before planting. The shelterwood was removed three growing seasons after planting. Four undercutting treatments were compared: (1) not undercut, (2) undercut the first year, (3) undercut the second year, and (4) undercut the first and second years. The top-clipping treatments were: (1) not top-clipped, (2) top-clipped 20 cm above ground line in the fall and overwintered in the nursery bed, (3) top-clipped 20 cm above the root collar after spring lifting and before outplanting.

One year after shelterwood removal, survival differed significantly ($p<0.05$) among treatments based on chi-square. Survival was highest for seedlings undercut the first year and top-clipped (79%) and lowest for seedlings undercut the first or second year but not top-clipped (59%). Survival between the outplanting sites differed significantly (66% vs 70%).

TWO-YEAR SURVIVAL AND GROWTH OF ARTIFICIAL NORTHERN RED OAK REGENERATION AT GETTYSBURG NATIONAL MILITARY PARK

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Overstory competition and foraging by white-tailed deer (*Odocoileus virginianus*) and small mammals are cited as reasons for regeneration failure in mixed-oak stands of Pennsylvania. At Gettysburg National Military Park, deer densities are high (>0.6 deer/ha), and the mixed-oak woodlots are lacking in seedling- and sapling-sized natural oak regeneration. To promote restoration of the woodlots to Civil War condition, we examined the effects of canopy conditions and browsing by deer and small mammals on the survival and growth of planted northern red oak (*Quercus rubra* L.) acorns and seedlings. In 1992, three study woodlots were selected as representative of the range of conditions in the Park, including high deer densities. Within each woodlot, three 0.20 ha circular canopy treatments were assigned. Each treatment was replicated three times within each woodlot. Treatments were closed canopy and partial and complete openings in the canopy. Within each canopy treatment unit, two paired fenced and unfenced plots were established, for a total of 18 pairs per woodlot. At each plot, 20 acorns and 4 bare-root (1-0) seedlings were planted. Survival and height were measured at the end of the second growing season after overstory treatment. In 1994, 55% of the 2,160 planted acorns had germinated; 86% of the 1,196 germinates had survived. Of the surviving seedlings: 813 were not browsed by deer or clipped by small mammals, 93 were browsed, 105 were clipped, and 13 were browsed and clipped. Woodlot and canopy level were significant predictors of acorn survival, with lowest survival (74%) in closed canopy compared to 86 and 88% for partial and complete openings. Significant predictors of height ($\bar{x}$ = 20cm) were woodlot, canopy level, and fencing. Height significantly increased with increasing amounts of direct sunlight (11, 16, and 29 cm for closed canopy, partial and complete openings, respectively). Fenced seedlings averaged 24 cm in height, whereas unfenced seedling mean height was 15 cm. Survival for the bare-root seedlings was 93%; there were no significant predictors of survival. Significant predictors of 1-0 seedling height ($\bar{x}$ = 35cm) were woodlot, canopy level, and fencing. Height was significantly greater in complete openings (42 cm) than in closed canopy (32 cm) or partial (32 cm) openings. Fencing significantly increased seedling height (31 and 39 cm for unfenced and fenced seedlings, respectively). Light levels at the partial and complete openings and the absence of browsing improved height growth of oak.

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THE EFFECTS OF TREESHELTERS ON THE GROWTH OF NORTHERN RED OAK PLANTED IN HARDWOOD CLEARCUTS AFTER FIVE GROWING SEASONS

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Treeshelters in artificial regeneration of hardwoods has shown promise for protection from browsing, increased survival, and accelerated early height growth. Because most of the early treeshelter information was based on studies that were 3 years old or less, it was not known if the early advantages of treeshelters continues after trees exited the shelters. The present study consists of 3 red oak plantings (CCC Camp, Crossville, and Scotia) that were established in harvested hardwood openings on the Mark Twain National Forest on the Salem Ranger District, near Salem, Missouri.

After five growing seasons, treeshelters improved survival only on one site. Nearly half (28) of the trees without shelters on the CCC Camp site died by the end of the second growing season compared to 5 trees with shelters. Total height growth for trees with shelters compared to unsheltered trees was increased by 23 percent for the CCC Camp planting, 41 percent for the Crossville planting, and 28 percent for the Scotia planting. However, annual height growth of sheltered trees declined compared to unsheltered trees between years 3 and 5. By the fifth growing season, 80 percent of the sheltered trees were tall enough to measure DBH compared to 46 percent of the unsheltered trees. Sheltered trees had significantly greater average diameters than unsheltered trees.

The 26 inch mean total height growth increase of sheltered trees over unsheltered trees can be attributed to accelerated growth during the first 3 years. Dry matter measurements taken 2 and 3 years after planting indicate that the accelerated height growth is not merely a growth reallocation process as assumed earlier, but an increase in total dry matter accumulation. The accelerated height growth declined after trees exited shelters, total biomass did not, indicating that the overall growth advantage continues after trees exit treeshelters.

EFFECTS OF TREE SHELTERS ON FIELD PERFORMANCE OF OAKS IN CALIFORNIA

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Blue oak (*Quercus douglasii*) and valley oak (*Quercus lobata*) are two species of native California oaks, endemic to the state, that are regenerating poorly in some locations. During the last 4 years we have conducted several studies on the growth and survival of these species in tree shelters. These studies have evaluated how well tree shelters work in protecting seedling from animal damage, including livestock browsing, deer and rodent herbivory and insect defoliation. We have also tried to determine how shelters affect seedling growth and morphology. Specific studies have evaluated how seedlings in tree shelters grow in comparison to seedlings in screen cages; how well tree shelters protect seedlings from cattle in grazed pastures; how different sizes (2, 4 and 6 feet) of tree shelters affect initial growth and survival; and how stunted, unprotected 3-year-old seedlings respond to retrofitting with tree shelters.

All studies have indicated that tree shelters can be very beneficial for establishing native oaks in California. Seedlings in shelters have grown far more rapidly than those in screen cages and have had far greater survival. Initially seedlings in shelters were very tall and spindly, but by the second field season, they had significantly greater diameter. These trends have continued during all 4 years since planting. Tree shelters secured with metal fence posts were also effective in protecting seedlings from cattle. While animals would occasionally rub against and bend the posts, the shelters were not seriously damaged as long as they were secured to the posts with wire. A study comparing different sizes of tree shelters has only been in place for 1 year, but results to date indicate seedlings in all sizes of shelters grew far more than the controls, and that initially, the 4-foot shelters produced the largest seedlings. Unprotected seedlings were partially defoliated by grasshoppers during the first summer, and while still alive, they have remained quite small. Finally, a study was designed to determine if shelters placed over previously established - and stunted - seedlings could improve growth. This study has demonstrated that the response is both dramatic and almost immediate. During the first year after retrofitting, approximately 60% of the seedlings doubled in height or more, with over half of these growing more than four times as tall as they had during the previous 3 years without protection.

These studies indicate that tree shelters show great promise for establishing native oaks on difficult sites in California. They have proved highly effective in protecting seedlings from a variety of animals intent on eating them, and have caused substantial increases in overall growth rates.

BOTTOMLAND OAK SEEDLING ESTABLISHMENT AND GROWTH ALONG A TOPOGRAPHICAL GRADIENT

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Erosional and depositional patterns in floodplains of the southern United States can create a heterogeneous composite of site conditions over a relatively small area. Minor changes in floodplain relief usually signify shifts in edaphic and hydrologic conditions, which can result in a change of tree species association. This composite of site types makes southern bottomland forests uniquely diverse, but it often leads to complex reforestation problems. This study was undertaken to determine if establishment and growth of bottomland oak species are influenced by elevational position on a floodplain site.

The study was established on an old-field near the confluence of the Tombigbee and Alabama Rivers, Alabama. The surface of the field decreased in elevation from a ridge to an old slough (1.2 m decrease over 126 m). Seedlings (1-0) and acorns were systematically planted along the gradient in the early spring of 1993. Water oak (*Quercus nigra* L.), willow oak (*Q. phellos* L.), swamp laurel oak (*Q. laurifolia* Michx.), Nuttall oak (*Q. nuttallii* Palmer), and overcup oak (*Q. lyrata* Walt.) were selected for this study, because these species are native to the area and exhibit different site preferences. Seedling height and root-collar diameter were measured after the first two growing seasons. Relative elevation of seedling and acorn planting spots was measured with a transit and leveling rod.

After two growing seasons, seedling survival ranged from 75% for Nuttall oak to 37% for willow oak. However, Nuttall oak seedlings showed the poorest relative height growth (56%), because of significant shoot dieback in the first growing season. Willow oak seedlings had the greatest relative height growth (263%). Seedling establishment from acorns ranged from 33% for Nuttall oak to 12% for overcup oak. Nuttall oak germinants were the largest after two growing seasons averaging 47 cm in height and 6 mm in root-collar diameter. Water oak germinants grew the least with an average shoot height of 20 cm and root-collar diameter of 2.5 mm. Preliminary analysis revealed no direct relationship between topographic position and seedling height or diameter growth. However, acorn establishment and seedling survival were strongly influenced by elevation.

DEVELOPMENT OF COPPICE REGENERATION IN A WATER OAK PLANTATION SUBJECTED TO TWO THINNING INTENSITIES

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Establishing an adequate stocking of oak can be a major problem when regenerating bottomland hardwood stands. Coppice is an important source of oak regeneration in natural stands, but little is known about the influence of a partial overstory on stump sprout development in oak plantations. To evaluate this question, a study of the survival and development of stump sprouts under two overstory thinning levels was established in a 28-year-old water oak (*Quercus nigra* L.) plantation.

The experimental stand was located on an old-field site near Winnsboro, LA. Before thinning, the stand was stocked with about 356 stems per acre averaging 6.6 inches DBH and the basal area was 86 square feet per acre. Eight treatment plots, each 1.4 to 1.5 acres, were established in the stand and assigned either a heavy or light thinning according to a completely randomized design. Plots assigned the heavy level were thinned to 103 stems per acre (residual basal area = 34 square feet per acre), and plots receiving the light level were thinned to 187 stems per acre (residual basal area = 52 square feet per acre). In each treatment plot three, 0.1-acre measurement plots, were systematically established. These 24 measurement plots were monitored through 7 years after treatment and the number of sprouts on each stump, sprout height, sprout-collar diameter and DBH of the largest sprout in each clump was recorded.

One year after treatment, 100% of the stumps sprouted regardless of thinning intensity. Seven years post-treatment, sprout clump survival under the heavy thinning level was 76%, compared to 53% under the light thinning level. Thinning level did not influence the average number of sprouts on a stump. Stumps from both treatments supported about 15 sprouts during the first growing season, but this number was reduced to 5 sprouts after the seventh growing season. Average DBH of the tallest sprout was significantly greater for the heavy thinning through year 5. However, sprout DBH averaged 1.0 inch under both thinning levels 7 years after treatment. Sprouts were significantly taller under the heavy thinning level between years 2 and 5, but all sprouts averaged 14.9 feet by year 7. Sprouts have maintained height and diameter growth through year 7 under both overstory thinning levels, but advantages of heavy basal area removal appear to be diminishing.

ECONOMICS OF DIRECT SEEDING NORTHERN RED OAK IN SOUTHERN IOWA

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As planting costs rise, direct seeding is more economically feasible, especially on old field sites where machinery can be used. Direct seeding of acorns is often more flexible than planting oak seedlings. Seed is easier to store and transport to the planting site and can be planted in the fall or in the spring after stratification. Seedlings from seed develop natural undisturbed root systems and do not have to recover from transplant shock.

Germination and survival percentages could be higher in large plantings than those achieved in small research plots. At current prices, if more than 28% of planted acorns result in an established seedling, all direct seeding techniques are cheaper than planting seedlings, and if more than 5% of acorns produce seedlings, only hand planting acorns is more costly than planting seedlings. At $132 for 600 seedlings, planting material cost/acre equals the cost of more than 6 bushels of acorns per acre, while planting rates of 1 - 3 bushels/acre can establish 600 seedlings/acre at the end of the first growing season.

Costs vary over time and among operations. When comparing hand planting acorns with machine planting seedlings, the most significant changes in the breakeven point come from changes in planting material costs. As planting material costs increase, hand planting acorns becomes more economically competitive with machine planting seedlings.

The use of machinery is not appropriate on some sites. Hand planting seed or seedlings is an expensive operation, but at current prices and survival percentages greater than 12%, the cost of hand planting acorns is less than the cost of hand planting seedlings.

More research is needed to establish guidelines for controlling competition during the first year. Once seedlings are established, management practices should be the same for seedlings from acorns as for planted seedlings.

A TREE SHELTERED DIRECT SEEDED RED OAK PROGENY TEST TRIAL

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If acorn predation is minimized and reliable techniques for accelerating height growth of juvenile seedlings are developed, establishing red oak (*Quercus rubra* L.) by direct seeding can be as effective and significantly cheaper than planting seedlings. Accelerated growth of planted oak seedlings has been demonstrated with tree shelters; however few references can be found on the benefits of tree shelters for direct seeding of red oak.

This study was established as a factorial experiment to compare height and survival of direct seedings from five open-pollinated red oak parent trees, representing a wide geographic origin, in combination with two tree shelter sizes (2' & 4') and two acorn sowing densities (3 and 6 acorns per plot). A total of 100 plots were planted at a spacing ranging from 10' to 15'. The study was established in mid-June of 1991 in a recent commercial clearcut that was located in the south central region of Pennsylvania. The clearcut was protected by an electrical deer fence for the first 3 years of the test. Competing vegetation in the area adjacent to the plots (4-6' dia.) was controlled by 2% glyphosate spray for the first two growing seasons.

After 4 years, the seedlings in the 4' tree shelters were significantly taller (Prob.> F = 0.0001) than those growing in the 2' shelters (5.2' vs. 4.3', respectively). There were no significant differences for the fourth-year mean heights among the five open-pollinated families, or between the acorn-density treatments. Additionally, no significant interactions were found among the main effects for fourth-year heights. Overall fourth-year survival was 98%.

POLLIN BIOLOGY OF QUERCUS

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Most of the potential seed crop in oaks is lost when pistillate flowers abort between the time of pollination and fertilization. In the present study the relationship between pollen tube (PT) growth and time of fertilization was examined. Pistillate flowers of northern red oak (*Quercus rubra* L.), black oak (*Q. velutina* Lam.), and white oak (*Q. alba* L.) were collected weekly from mid-April to mid-September and processed for light and fluorescence microscopy.

Northern red oak (NRO) and black oak (BO), members of the Erythrobalanus subgenus (red oaks), are pollinated in central Missouri during late April and early May, respectively, and require two growing seasons for their flowers to develop into acorns. At anthesis, the pistillate flowers of both species have small locules with rudimentary ovules. By the end of the first summer, the ovules were still rudimentary, although the locules had enlarged slightly. In both species, soon after the pollen grain adheres to the stigmatic surface, the PT elongates from the aperture and penetrates the epidermis of the stigma. A callose plug is quickly synthesized in the PT, isolating the discharged contents from the pollen grain that soon falls off the stigma. Many callose plugs were seen within the PTs in the solid transmitting tissue of the style and may be synthesized to maintain turgor in the tip of the PT as it advances or they may be an incompatibility reaction. During the first growing season, the pollen tubes stop elongating by mid May before they reach the junction of the three styles at about the level of the visible portion of the perianth. In the spring of the second growing season, PTs resume elongation after the ovules differentiate into a nucellus and integuments. The PTs of NRO entered the compitum and locules about May 21 and those of BO on June 4. In both species, the megaspore mother cell was undergoing meiosis before the PTs approached the ovules in the locules. Fertilization was estimated to occur during the weeks of June 11 for NRO and June 25 for BO.

The pistillate flowers of White oak, a member of the Lepidobalanus subgenus (white oaks), mature into acorns in one growing season. The course of the PTs is similar to that of the other two species, except that after the PTs cease growth in mid May, they resume elongation in early June, and fertilization occurs during the week of June 11. This report provides temporal and kinetic data for understanding the differences in reproductive cycles of the red and white oaks.

HYDRAULIC RESISTANCE ASSOCIATED WITH GRAFT UNIONS IN NORTHERN RED OAK (*QUERCUS RUBRA* L.)

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Xylem hydraulic parameters were quantified in stems containing graft unions of either juvenile or reproductively mature tissue as well as in stems containing the transition zone (bud scale node) between the current-year's and 1-year-old growth by perfusing stems with water. Hydraulic resistance (R_h) was quantified for entire stem segments containing either a graft union or a bud scale node at its midpoint as well as for sub-segments without graft unions or bud scale nodes. To compare resistance values for sub-segments, the proportion of the total segment resistance represented by a sub-segment (R_h) was divided by the proportion of the total segment's length represented by the sub-segment (L'). A value of 1.0 for the R_h'/L' ratio indicates that the presence of a graft union or bud scale node did not add to total segment resistance.

In juvenile grafts, the presence of a graft union increased segment resistance by 126% when compared to scion tissue and by 94% when compared to rootstock tissue. In mature grafts, the presence of a graft union increased segment resistance by 259% when compared to scion tissue and by 81% when compared to rootstock tissue. The presence of a bud scale node increased flow resistance by 30% and 36% in juvenile and mature stems, respectively. The R_h'/L' ratio was comparable between sub-segments containing the graft union (1.23 and 1.66 for juvenile and mature grafts, respectively) and sub-segments containing the bud scale node (1.49 and 1.69 for juvenile and mature grafts, respectively).

It appears that the graft union represents a region of relatively high flow resistance, and is comparable to bud scale nodes in the transition between current-year shoots and 1-year-old growth. In both cases, the vascular transition is probably characterized by a large number of vessel end walls. Because the leaf area supported by each sub-segment of an entire stem segment is equal and given the relationship between R_h and leaf specific conductivity (LSC) (LSC = leaf area/R_h), it is concluded that the presence of a graft junction causes a substantial reduction in LSC, reducing the xylem's capacity to supply water to the transpiring foliage.

GROWTH OF NORTHERN RED OAK ADVANCE REPRODUCTION AS A FUNCTION OF SPATIAL AND TEMPORAL VARIATION IN CALCULATED SOLAR RADIATION

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The relationship between seedling growth and calculated exposure to sunlight was studied in four French plantations of *Quercus rubra* L. in which advance reproduction was present in exceptional uniformity and density (86-160,000 stems/acre). In June 1993, canopy photographs were taken with a 35 mm camera equipped with a 16 mm lens and positioned horizontally at the height of NRO seedlings or saplings at that point. In 3 plantations, 48 or 49 systematically located points were sampled; in the fourth only 35 points were sampled to avoid recent canopy gaps. At each photo point, 2-5 seedlings representing the "seedling canopy" at that location were harvested and the following measured: seedling height, 1993 height increment, stem radius at base, stem age, and radial increment for each of previous 5 years. Image files created from the photos were analyzed to determine unobstructed exposure to the sun's disk based upon the position of the sun at 1-minute intervals for each day during the growing season (April - September), and these data were converted to photosynthetically active radiation (PAR) using meterological data from stations nearby and published algorithms.

Regressions of plant size or growth variables on PAR calculated for various portions of the growing season were done after randomly reducing data set by 20%. Expressions of calculated PAR explained a significant amount of variation in all size/growth variables at three plantations and in several size/growth variables at the fourth. In general, PAR explained the least spatial variation in size/growth at the site with the lowest site index. Some expression of relative basal area increment was most consistently explained by calculated PAR, with multiple R2 of 0.510 to 0.825, depending upon plantation. Considering the variables in all significant regressions, June and August PAR were most important. July PAR was least important, perhaps due to water deficits in that month.

RELATIONSHIP BETWEEN MOTHER TREE AND PROGENY

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The relationship between mother tree and seedlings was examined in 1+0 seedlings reared from half-sib (open-pollinated) acorns collected from 30 individual mother trees representative of northern red oak (*Quercus rubra* L.), northern pin oak (*Q. ellipsoidalis* E.J. Hill), and their hybrids. The 30 trees were selected on the basis of leaf, canopy, and stem characteristics to provide 10 trees to represent each of these groups. The position of the mother trees along the spectrum between northern red and northern pin oak was further quantified using leaf morphometry and isozyme analysis.

Acorns of the northern pin oak group were smaller than those from the other two mother tree groups; acorns from the northern red oak and hybrid mother trees were not distinguishable. Seedling height, root collar diameter, and number of permanent first-order lateral roots from either northern red oak or hybrid mother trees were also similar and larger than those of seedlings from northern pin oak mother trees. When seedling characteristics were plotted as a function of acorn volume, northern pin oak seedlings formed a distinct cluster of data as did northern red oak plus hybrids.

Mother tree leaf morphometry also distinguished two groups of mother trees; northern red oak and hybrid mother trees fell into one group, northern pin oak fell into a second group. Discriminate analyses misclassified 33% of leaves between northern red oak and hybrids, and 12% of northern pin oak leaves as hybrid leaves; however, none of the northern red oak or hybrid leaves were misclassified as northern pin oak.

The isozyme data for mother trees in the northern red oak and hybrid groups were consistent with the leaf morphometry, acorn, and seedling data. Isozymes of 6 enzyme systems representing 9 putative loci were analyzed electrophoretically. Isozyme analyses for northern pin oak mother trees is in progress.

In summary, all data to date suggest that mother trees and seedlings in this study represent two, not three distinct groups - northern pin oak, and northern red oak plus hybrids. None of the criteria, to the extent they have been tested, were able to discriminate between the northern red oak and hybrid trees selected for use in this study. Conversely, all characterization methods employed discerned northern pin oak mother trees. Much data collection and analysis remain; in particular, isozyme analysis of pin oak mother trees and growth after outplanting could provide different perspectives, not evident with the data to date.

DOES GRAFTING REJUVENATE CUTTINGS? MERISTEM SELECTION AS AN ALTERNATE HYPOTHESIS

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Grafting and rooting trials were performed to follow shoot development and rooting ability of individual buds of a mature seed-producing northern red oak (*Quercus rubra* L.). Sixty-four matched pairs of dormant twigs were chosen with a total of 701 buds identified by parent twig and position on the twig. Apical bud clusters and individual lateral buds (meristems) from one randomly selected twig of each pair were grafted onto potted northern red oak seedlings and stimulated to develop into shoots. Buds from the paired counterparts were left on the tree to develop normally.

In situ, shoots developed from 100%, 75% and 18% of terminal buds (Position I), lateral buds within the distal 1/3 of the twig (Position II), and lateral buds within the proximal 2/3 of the twig (Position III), respectively. When grafted, shoots developed from 39%, 54%, and 42% of the buds from the same positions, respectively. This indicated that shoots from grafted and *in situ* meristems originated from two positionally different populations of buds. Cuttings from all shoots were subjected to a rooting trial. Overall, cuttings from grafts had greater rooting success (48%) than cuttings developed *in situ* (14%). However, for grafted and *in situ* bud pairs which both produced shoots, rooting success was independent of grafting. For shoots developed *in situ*, rooting was not significantly related to position on the twig. For cuttings from grafts, rooting was significantly related to position on the twig with 25%, 46%, and 67% success for Positions I, II, and III, respectively.

Though differences in the rooting ability of shoots from widely varying crown positions are well known, results suggest that differences in rooting success occur on a much smaller scale, among meristems positioned along a twig. Our results suggest that buds which normally develop into shoots *in situ* are not as competent to root (and perhaps more determined in their developmental fate) as those at more proximal portions of twigs that usually maintain dormancy *in situ* but form shoots when grafted. Although increased rooting success mediated by grafting is often attributed to physiological or ontogenetical rejuvenation of grafted meristems by juvenile rootstock, these results suggest that grafting may serve to select for those meristems with potential for high rooting success by allowing their development into shoots and indirectly select against meristems that normally exhibit low rooting success through decreased shoot development.

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Research results and ongoing research activities in field performance of planted trees, seedling propagation, physiology, genetics, acorn germination, and natural regeneration for oaks are described in 29 abstracts.

KEY WORDS: Plantations, propagation, regeneration.